ON THE ELECTRON PRODUCTION RATE IN THE F_2 REGION OF THE IONOSPHERE

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ABSTRACT. A column of unit cross section of the F_2 region extending from the "bottom" to the height of its maximum electron density is divided into four columns of equal length. Mean production rate in each of the columns is calculated. For this purpose, diurnal variation of the total number of electrons in each of the columns and the height variation of the attachment coefficient suggested by Ratcliffe *et al* (1956) are utilised.

This method of computation leads to a regular consistent diurnal variation of the electron production rate with a single peak at about half an hour before noon time and eliminates the anomalous results that are sometimes obtained when other methods of computation are employed.

INTRODUCTION

The electron production rate $q(h)$ in the F_2 region of the ionosphere at any height h may be calculated from the equation :

$$q(h) = \frac{dN(h)}{dt} + K(h) \cdot N^k(h) \tag{1}$$

where $N(h)$ is the electron density and $K(h)$ is the loss coefficient at the height h, the value of k depending upon the electron loss process is 1 or 2.

One may also consider the mean production rate $\bar{q}$. This computation (Datta, 1957) is based on the diurnal variation of the total number of electrons n in a column of unit cross section from the "bottom" to the height of maximum electron density. The equation utilised is

$$\frac{dn}{dt} = \bar{q} \cdot ym - \bar{\alpha} \left(\frac{n}{y_m} \right)^2 \cdot y_m \tag{2}$$

where $\bar{\alpha}$ is the mean recombination coefficient and y_m is the layer semithickness. For parabolic distribution of electron density $\bar{\alpha} = 1.2\ \alpha_m$ and under equilibrium conditions $\bar{q} = \frac{8}{15}\, q_m$ where α_m and q_m are the recombination coefficient and electron production rate at the height of maximum electron density.

To determine $q(h)$ from Eq. (1) one assumes either a fixed value of the loss coefficient or its symmetrical diurnal variation. When calculations are made with the latter assumption the $q(h)$ values so determined show necessarily diurnal symmetry having anomalous midday dip and sometimes zero, even negative values. This happens, in particular, at the maximum electron density height due to the well-known midday "bite out" in the diurnal variation of maximum electron density in the F_2 region. Both the calculations, namely, that assuming symmetrical diurnal variation and that with a fixed value of the loss coefficient are affected by the bodily movement of the layer as a whole and by dilution and contraction of the layer due to thermal changes and electronic drift.

When computations are made from the diurnal variation of n utilising Eq. (2) the anomalous negative and zero values of the electron production rate obtained at the height of maximum electron density height, disappear. The anomaly of middy dip in the diurnal variation of the production rate, however, persists though less markedly. The method also minimises the effects of dilution and of contraction of the layer due to thermal changes and electronic drift on the production rate computation. However, it does not give any information about production rate variations at different parts of the F_2 region.

In the method of analysis, as presented in this paper, a column of unit cross section extending from the "bottom" to the height of maximum electron density is divided into four columns of equal length and mean electron production rate in each of the columns is computed from the diurnal variation of the total number of electrons in each of the columns. Effects of layer movement as a whole, and layer contractions and dilution due to thermal changes and electronic drift are then minimised, since the computations are from the total number of electrons in unit column in some definite fraction of the layer thickness, irrespective of the total layer thickness and the layer height. The data actually used for computation for the F_2 region were those of Slough : mean hourly values of $N(h)$ at a series of heights for the month of January, 1950, on international quiet days computed by Schmerling and Thomas (1956). For the height variation of the attachment coefficient that suggested by Ratcliffe *et al.* from night time observations over Slough, Watheroo and Huancayo, was utilised. "Tables of F_2-layer Electron Density on International Quiet Days" were obtained from Radio Group, Cavendish Laboratory, Cambridge, England.

It is proposed to make a similar analysis in a subsequent paper for the F_2 region over Haringhata when the work, already in progress in this laboratory for the determination of the distribution of electrons in "mean quiet F_2-layer" and a model for the height variation of the loss coefficient over Haringhata, is completed.

THE METHOD

A column of unit cross section extending from the "bottom" of the F_2 region to the height of maximum electron density is divided into a number of columns of equal length. Let n_r be the total number of electrons in the rth unit column —the first column being the lowest one. Then

$$n_r = \int_{(r-1)\frac{T}{x}}^{r \cdot \frac{T}{x}} N(h) \cdot dh \qquad \ldots \quad (3)$$

where T is the thickness of the layer from the "bottom" ($h_0\,F_2$) to the height of maximum electron density ($h_m F_2$) when height is measured from the bottom of the layer and x is the number of equal unit columns. It is to be noted that the total number of electrons n in the unit column extending from the "bottom" to the maximum electron density height is given by

$$n = \int_{h_0\,F_2}^{h_m\,F_2} N(h) \cdot dh = \sum_{1}^{x} n_r \qquad \ldots \quad (4)$$

In case of a parabolic region, it can be shown that

$$n_r = \frac{1}{x} \left[1 - \frac{1}{3x^2} \{1+3\,(x-r)^2+3\,(x-r)\} \right] \cdot T\,N_m \qquad \ldots \quad (5)$$

where T is the semi-thickness of the parabolic region and N_m is the maximum electron density.

The diurnal variation of n_r is governed by the equation

$$\frac{dn_r}{dt} = Q_r - L_r \qquad \ldots \quad (6)$$

where Q_r is the total production rate and L_r is the total loss rate in the column considered and they are given by

$$Q_r = \int_{(r-1)\,\frac{T}{x}}^{r \cdot \frac{T}{x}} q(h)\,dh \qquad \ldots \quad (7)$$

and

$$L_r = \int_{(r-1)\frac{T}{x}}^{r \cdot \frac{T}{x}} K(h)\,.\,N^k(h)dh \qquad \ldots \quad (8)$$

$k = 1$ when the electron decay process is attachment type.

and $k = 2$ when the electron decay process is recombination type.

If q_r be the mean electron production rate in the rth column, then

$$q_r = \frac{x}{T} \cdot Q_r \qquad \ldots \quad (9)$$

Thus from the diurnal variation of n_r and the values of L_r, Q_r [from (6)] and hence the mean rate of production q_r [from (9)] can be computed.

Values of n_r and L_r may be calculated by numerical integration utilising Eqs. (3) and (8). These computations obviously require knowledge of the height variation of the loss coefficient $K(h)$, height distribution of electron density $N(h)$ and the electron decay process.

RESULTS

Recent work of Ratcliffe *et al.* indicates that the electron decay process in the F-region above 240 Km is of the attachment type. From night time observations (Ratcliffe 1956) over Slough, Huancayo and Watheroo they conclude that the attachment coefficient $K(h)$ at a height h between 250 Km and 350 Km is given by

$$K(h) = 10^{-4} \cdot \exp\left(\frac{300-h(K_m)}{50}\right) \text{sec.}^{-1} \qquad \ldots \quad (10)$$

For our purpose, Eq. (10) is extrapolated to a height of 200 Km as shown in figure 1.

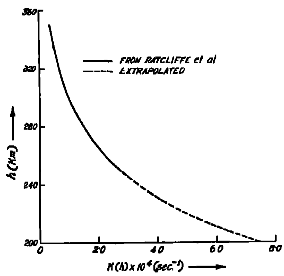

Fig. 1. Variation of the attachment coefficient with height.

A column of unit cross section from the bottom to the height of maximum electron density in the F_2 region is divided into four columns of equal length. From the "Tables of F_2-layer electron density on international quiet days", height distribution of electron density for every hour was drawn and total number of electrons in each of the four columns was calculated by Simpson's rule for numerical integration. The diurnal variation of the total number of electrons in a column of unit cross section from the bottom to the height of maximum electron density is shown in figure 2. figure 3 shows the diurnal variation of the numbers n_1, n_2, n_3 and n_4 of electrons in the 1st, 2nd, 3rd and 4th columns respectively when taken in order from the bottom.

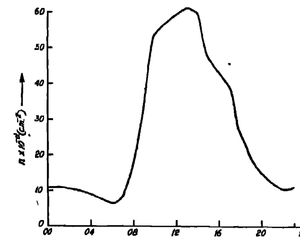

Fig. 2. Diurnal variation of the total number of electrons in a column of unit cross section extending from the bottom to the height of maximum electron density.

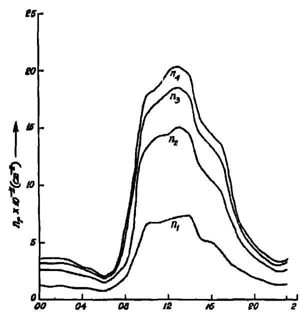

Fig. 3. Diurnal variation of the number of electrons n_1, n_2, n_3 and n_4 in the 1st, 2nd, 3rd and 4th columns respectively when taken in order from the bottom.

Hourly values of the loss rate in each column were also calculated by numerical integration utilising Eqn. (8) by Simpson's rule. $K(h)$ values given by (10) were used for the purpose.

To obtain half hourly values of $\frac{dn_r}{dt}$ for each of the columns, a linear change between the hourly values of n_r was assumed. For each column, mean of the two hourly values of L_r was taken as the half hourly value between the two hours. Thus half hourly values of mean production rate in each column were calculated from Eqs. (6) and (9). The diurnal variations of mean production rates q_1, q_2, q_3 and q_4 in the 1st, 2nd, 3rd and 4th column respectively are shown in figure 4.

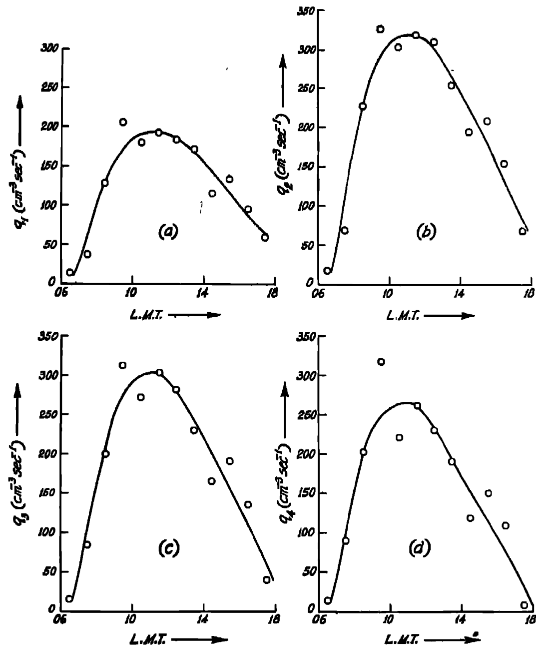

Fig. 4. Diurnal variation of mean production rate q_1, q_2, q_3 and q_4 in the 1st, 2nd, 3rd and 4th columns respectively when taken in order from the bottom.

The production rate Q of the electrons in a column of unit cross section from the bottom to the height of maximum electron density height is given by

$$Q = \frac{T}{4}\,(q_1+q_2+q_3+q_4) \qquad \dots \quad (11)$$

Figure 5 shows that diurnal variation of the prouction rate Q. Figure 6 shows the diurnal variation of the mean electron production rate Q/T in the F_2-region. For comparison the value of Q from the hypothesis of Bradbury (1938) for the formation of the F_2-layer, may be calculated as follows.

If a gas of constant scale height H is ionized by a monochromatic radiation, then the value of $q(h)$, when the solar zenithal angle is χ, is given by the expression due to Chapman (1931a)

$$q(h) = q_0 \exp\,(1-Z-e^{-z} \sec \chi) \qquad (12)$$

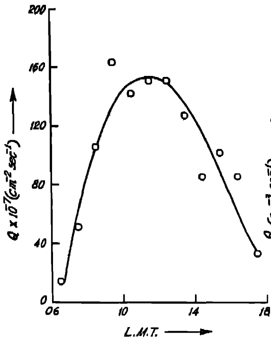

Fig. 5. Diurnal variation of electron production rate Q in a column of unit cross section extending from the bottom to the height of maximum electron density.

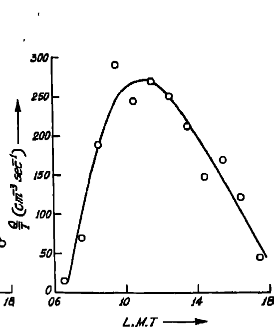

Fig. 6. Diurnal variation of the mean electron production rate Q/T in the F_2-region.

Half hourly values of electron production rate Q in a column of unit cross section entending from bottom of the F_2 region to the maximum electron density height

TABLE I

Hour L. M. T.	$Q \times 10^{-7}$ per cm^2 per sc
0630	13
0730	51
0830	106
0930	163
1030	141
1130	151
1230	151
1330	127
1430	86
1530	102
1630	86
1730	33

where $Z = \frac{h - h_0}{H}$ and h_0 is the height of maximum production rate q_0 when $\chi = 0$.

According to Bradbury, F_1 and F_2 layers are both produced by the same ionization process with the height of peak production rate near the level of F_1 layer peak and the F_2 layer peak is formed due to the rapid decrease of the electron loss rate above F_1 layer. According to this hypothesis the value of Q in the F_2 region when the solar zenithal angle is χ, is given by

$$Q = \int_{h_0F_2}^{h_mF_2} q(h)dh = q_0\, H\cos\chi\,\{\exp\,(1-e^{-z_2}\sec\chi) - \exp(1-e^{-z_1}\sec\chi)\} \quad \ldots \quad (13)$$

where $$Z_2 = \frac{h_mF_2 - h_0}{H}$$

and $$Z_1 = \frac{h_0F_2 - h_0}{H}$$

According to Ratcliffe *et al*

$$q_0 \doteq 280\,(1+1.4\times10^{-2}\bar{R})\ \mathrm{cm}^{-3}\cdot\mathrm{sec}^{-1} \quad \ldots \quad (14)$$

where $\bar{R}$ = monthly average relative Zürich sunspot number.

$h_0 = 180$ Km and $H = 45$ Km.

For the month of January 1950 ($\bar{R} = 100$) at Slough, the value of Q at noon from the expression (13) is found to be 105×10^{7} cm^{-2} sec.$^{-1}$ while the value of Q at noon shown in Table I is 151×10^{7} cm.$^{-2}$ sec.$^{-1}$

CONCLUSION

Diurnal variations of mean electron production rate in different parts of the F_2 region, when computed by taking account of the height variation of attachment coefficient suggested by Ratcliffe *et al.* show quite consistent results. The mean production rates have all maximum near about 1130 hr. Unlike other methods of electron production rate computation, this method does not lead to anomalous value or midday dip in the diurnal variation.

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